PEM Fuel Cell Stack Development and System Optimization

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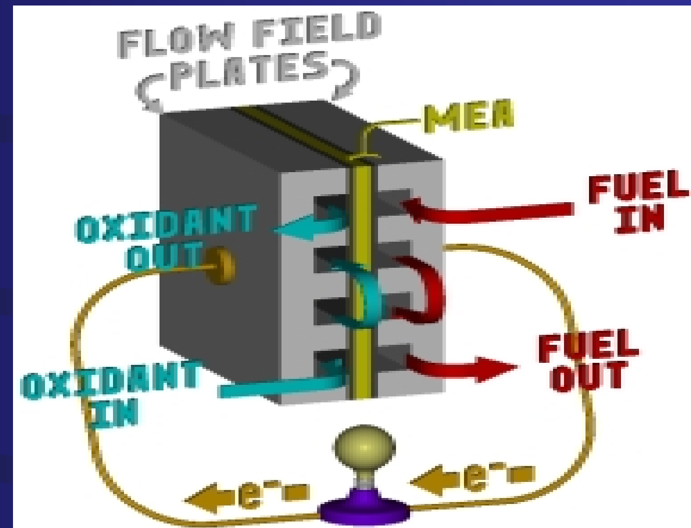
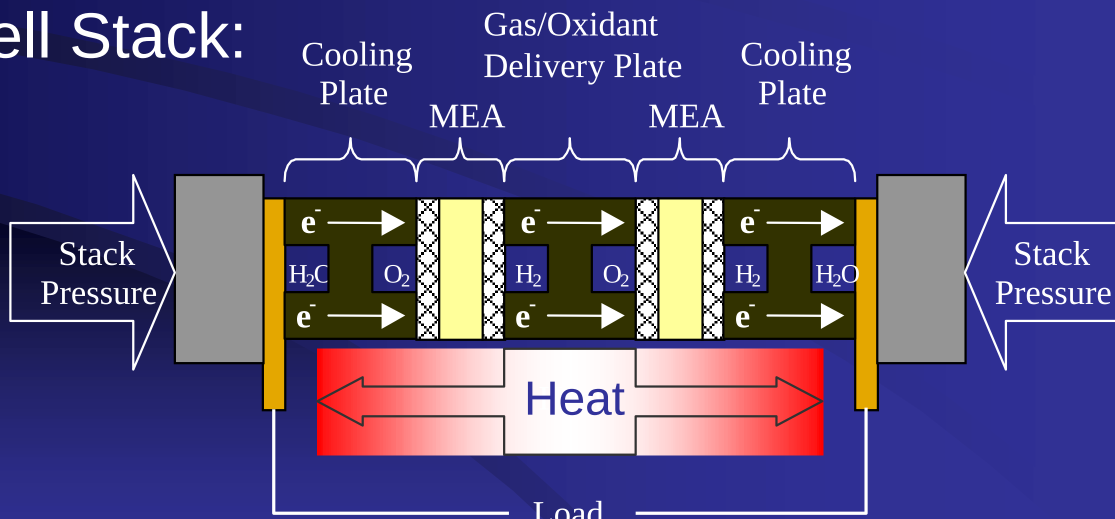
PEM Fuel Cell and Stack

A PEM Fuel Cell:



A PEM Fuel Cell Stack:



PEM Fuel Cell

- History of Development
  - GE (Gemini spacecraft, 1959-1982)
    - > UTC-Hamilton Standard and Siemens AG (for the air-independent submarine, mid-1980s)
  - Ballard Power System Ltd. (1983, 1990s, …)
  - Many Others
- Core Technology
  - MEA (Membrane Electrode Assembly)
  - Stack
- Key Technical Problems of Stack/System Design
  - Heat Management
  - Water Management
  - Costs

Proof of Concept Fuel Cell E-Vehicles

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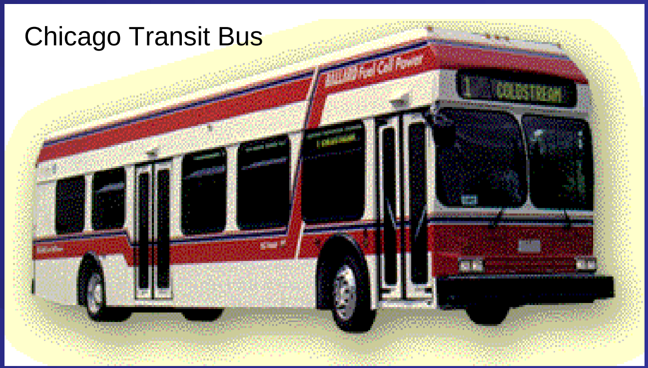
Automotive Companies and Transit Authorities Using Ballard Fuel Cells

- GM
- Ford
- DaimlerChrysler
- BC Transit
- Chicago Transit
- Volkswagen
- Honda
- Nissan
- Volvo



From other Manufacturers

PEM Fuel Cell Research at University of Victoria

- **Next Generation Fuel Cells for Transportation (NGFT) (1994~1999)**
  - Carried out in the *Institute for Integrated Energy Systems*
  - Jointly supported through a *Collaborative Research Grant* of 3.4 M by Natural Science and Engineering Research Council (NSERC) of Canada, British Gas Canada and Ballard Power Systems Ltd.
- **Research on Fuel Cell Powered Electrical Bicycles** (2000 ~ ...)
- **Etc.**

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NGFT Fuel Cell Research

- **Research Groups:**
  - NGFT program
  - tubular-cell stack development
  - radiator stack development; low-cost fuel cell plate manufacturing; and fuel cell system design and optimization
  - new fuel cell membrane development
  - fuel cell modeling
- **Outcome:**
  - extensive new intellectual properties, transferred to Ballard
  - a large number of students and professionals who now play active roles in the fuel cell industry
  - a modern fuel cell research laboratory

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Research on Fuel Cell Powered Electrical Bicycles

- To be carried out as a collaborative research program
  - Palcan Fuel Cell Ltd.
  - Innovation Center, National Research Council (NRC) of Canada
  - University of Victoria
- To focus on the development of
  - stack and system modeling, design and optimization tools
  - testing of fuel cell powered electrical bicycles and scooters

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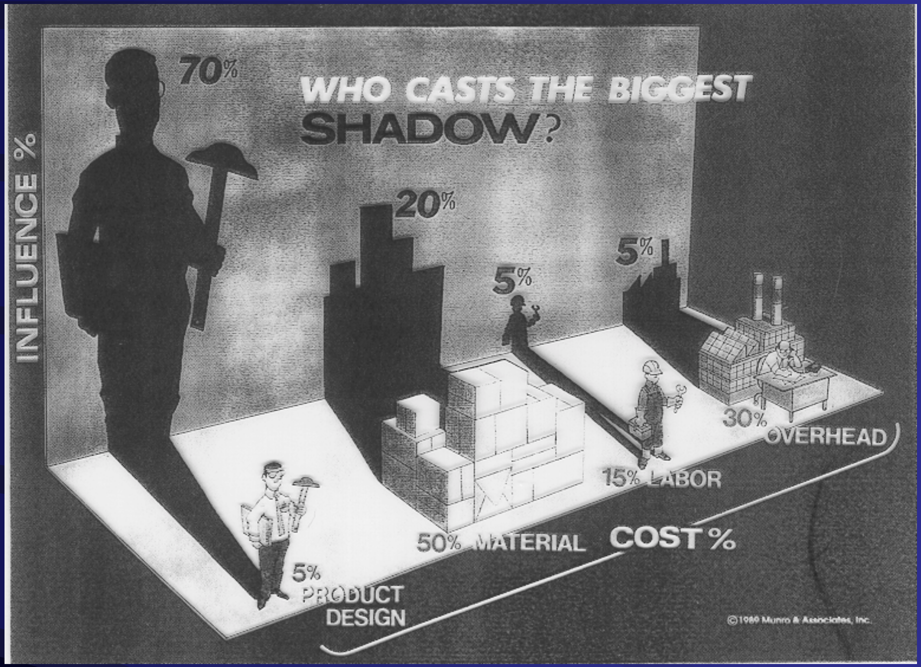
PEM Fuel Cell System Modeling

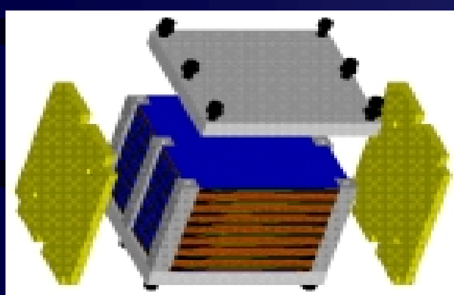
- **Types of Model**
  - Performance model
  - Cost model
  - Parametric solid models
- **Modeled Subjects**
  - Fuel cell
  - Fuel cell stack
  - Ancillary devices
  - Fuel cell system
- **Functions**
  - Identifying technology/cost challenges
  - Component design optimization
  - Integrated concurrent engineering design and system optimization

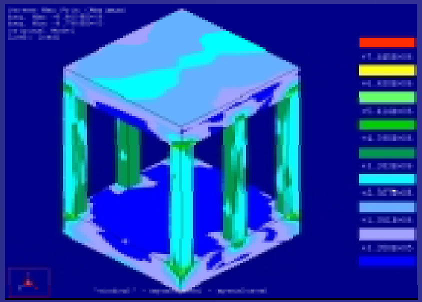
Importance of Product Design

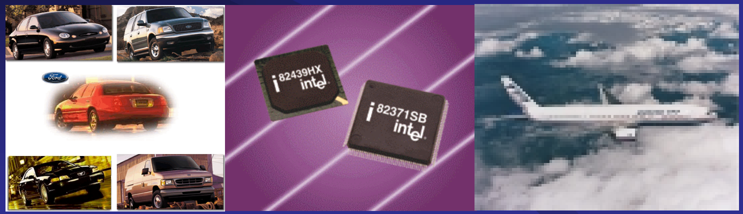


- Direct cost of design in product development: **5%**
- Influence of design to the entire product cost: **70%**

Quantitative Concurrent Engineering Design Using Virtual Prototyping-based Design Optimization







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A Novel Transportation PEM Fuel Cell Stack Design

Tri-stream, External-manifolding, Radiator Stack (TERS)

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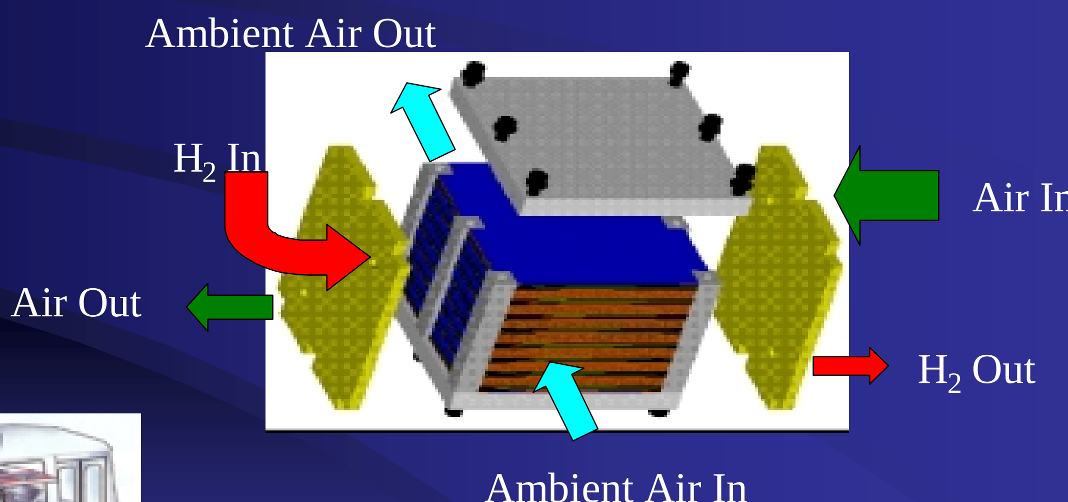


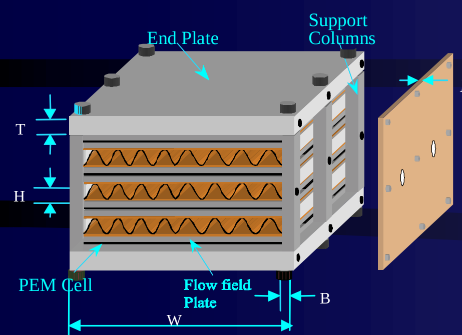
Research Issues

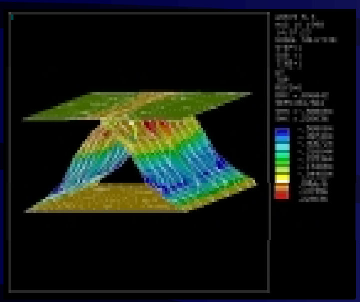
- Virtual Prototyping Using Pro/ENGINEER
- Validation of Computer Modeling and Analysis Results
- Development of A Software Tool for Virtual-prototyping Based Design Optimization
- Concurrent Engineering Design through Multiple Objective, Global Optimization

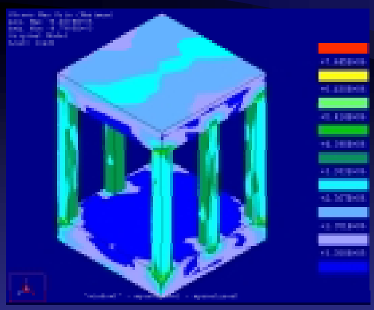
Virtual Prototyping-based Design Optimization

- **Virtual Prototype Construction**
  - a parametric CAD model using Pro/ENGINEER
- **Virtual Prototype Testing**
  - built-in finite element analysis module for structure integrity, heat transfer capability and dynamics stability assessments
  - manufacturing planning module for production cost and manufacturability estimation; and
  - dedicated external software modules for measuring specific functional performance of the design.
- **Solution Method**
  - Adaptive Response Surface Method (ARSM)

Virtual Prototyping-based Design Optimization
Adaptive Response Surface Method (ARSM)







Virtual Prototyping

Computer Analysis and Simulation Tools -- Pro/E and Research Programs

Call

Function Values

Experimental Designs

Model Fitting

Call

Function Values

Global Optimization

Design Space Reduction

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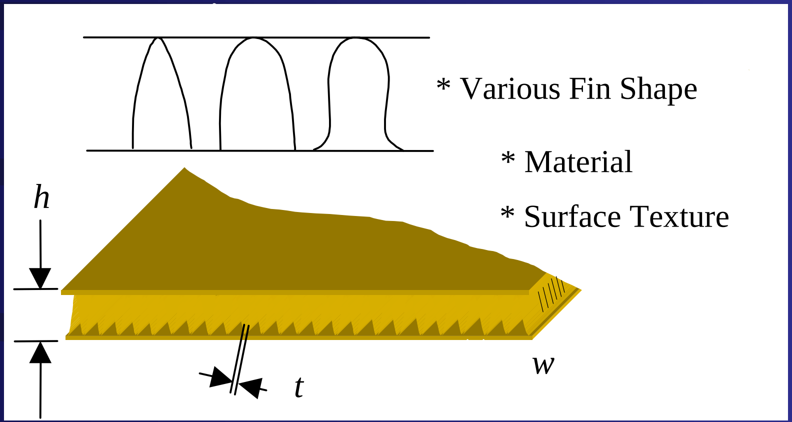
Optimal Design of the Key Component of TERS — Multi-functional Panels



Design Considerations

- Heat transfer
- Compensation of thermal and hydro expansion
- Electrical conductivity

Design Variables

Fin Wavelength, ***w***, thickness, ***t***, panel height, ***h***, surface texture, material, and fin shape

Formulation of Design Problem

Objectives

Minimize | Panel Stiffness - Ideal Stiffness |

Maximize Outlet Temperature

Constraints

Maximum Air Flow Rate < Constant 1

Panel Deformation Percent Difference < 10%

Outlet Temperature > 320 K

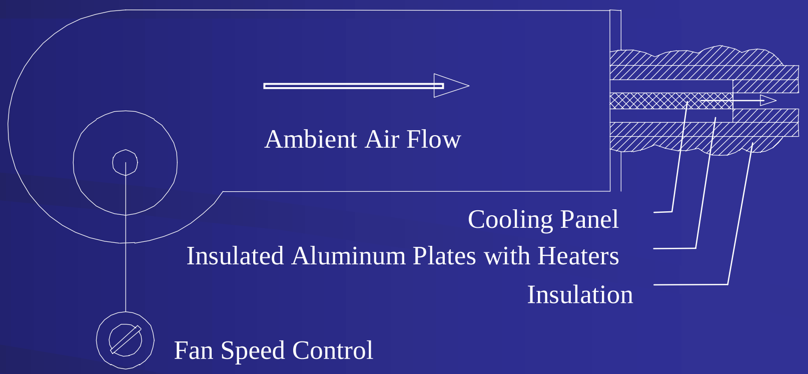
Conductivity > Constant 2

Parameter Bounds

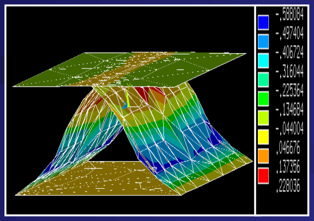
Validation of the Computer Model (Multi-functional Panels)

- **Heat Transfer**

Mathematical Modeling +



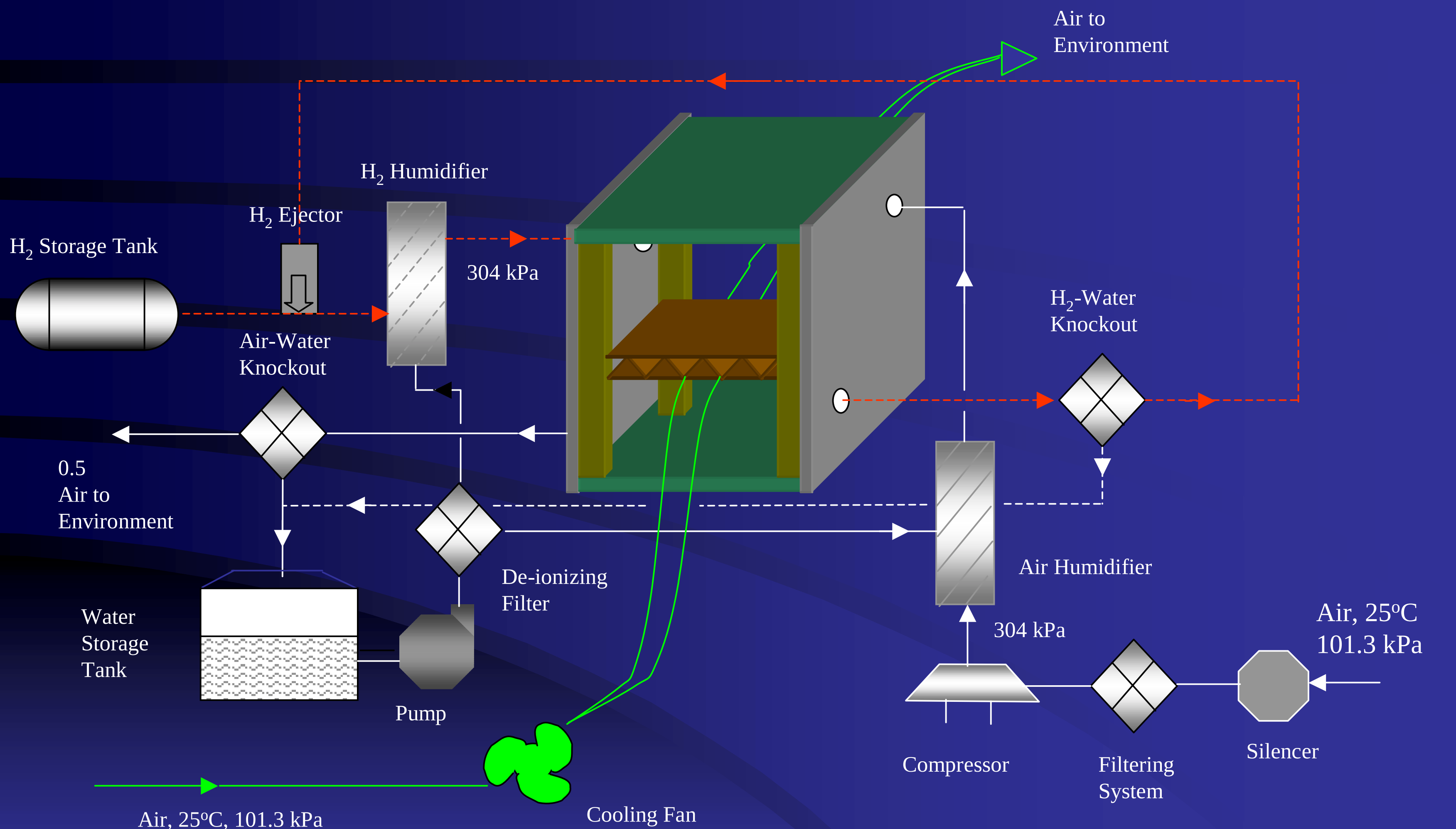
- **Panel Stiffness**

Virtual Prototyping  + 

Compression Test

ARSM for Integration and Optimization

Modeling of the TERS Fuel Cell System



Optimization of the TERS Fuel Cell System

Design Parameters:

- five geometric parameters
- one operational parameter
- one system configuration parameter

AirSt	1.3 ~ 2.5
StackW	100 ~ 240 mm
ColW	10 ~ 30 mm
NCell	10 ~ 60 mm (Layout a) 10 ~ 130 mm (Layout b)
FinH	4 ~ 15 mm

Design Objectives:

cost, power densities, efficiency and net power

Design Constraints:

structure integrity and system size

Integrated Concurrent Engineering Design:

$$\min_{X} f(X) = \min_{X} \left\{ \lambda_c \sum f_c(X) - \lambda_p \sum f_p(X) \right\}$$

Results of Design Optimization

- **Multiple Functional Panel Design**
  - Panel thickness, *t*, dominants the stiffness; panel height, *h*, dominants the heat transfer capability;
  - Optimum at: *h=4, w=9, t=0.012 (mm)* with an ideal panel deformation of *0.0341 mm* under loads.
- **TERS Fuel Cell System Design**
  - Design considerations: cost, performance (net power, efficiency, power densities), structure integrity, and space constraints.
  - Increased system power density by *43%*,
  - Reduced system costs by *16%*, and
  - Obtained the global optimum of system design in *hours*.

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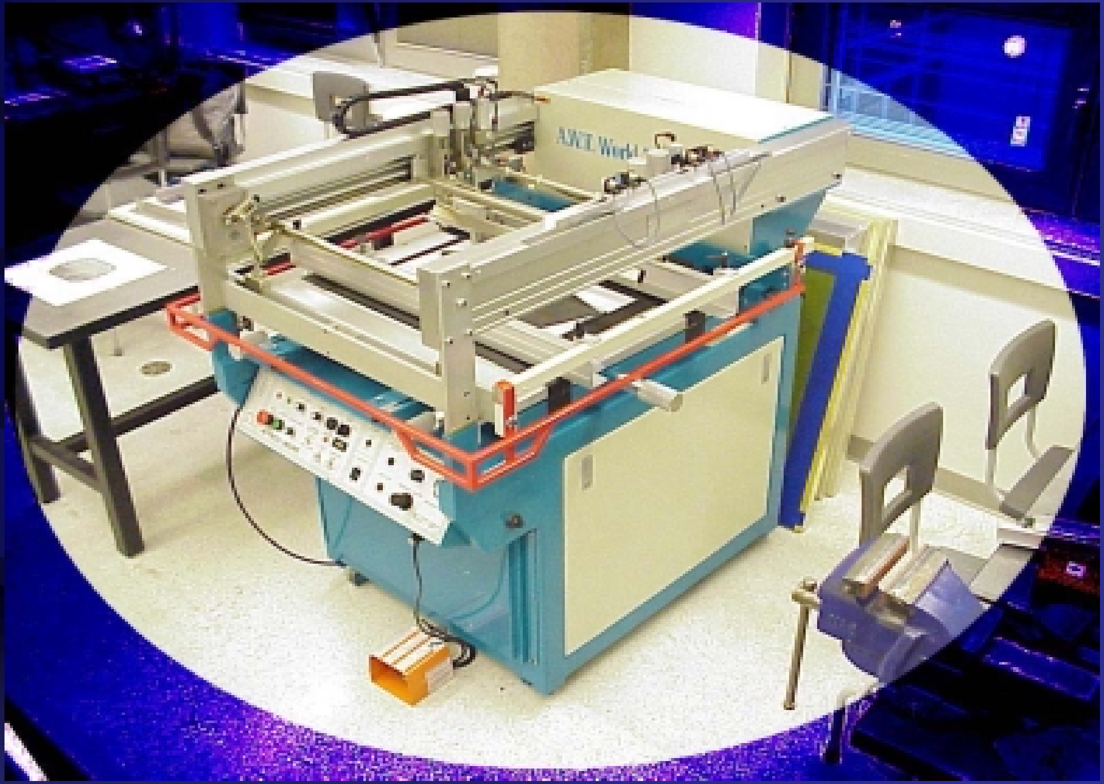
Screen Printing Fuel and Oxidant Delivery Plate Manufacturing Method



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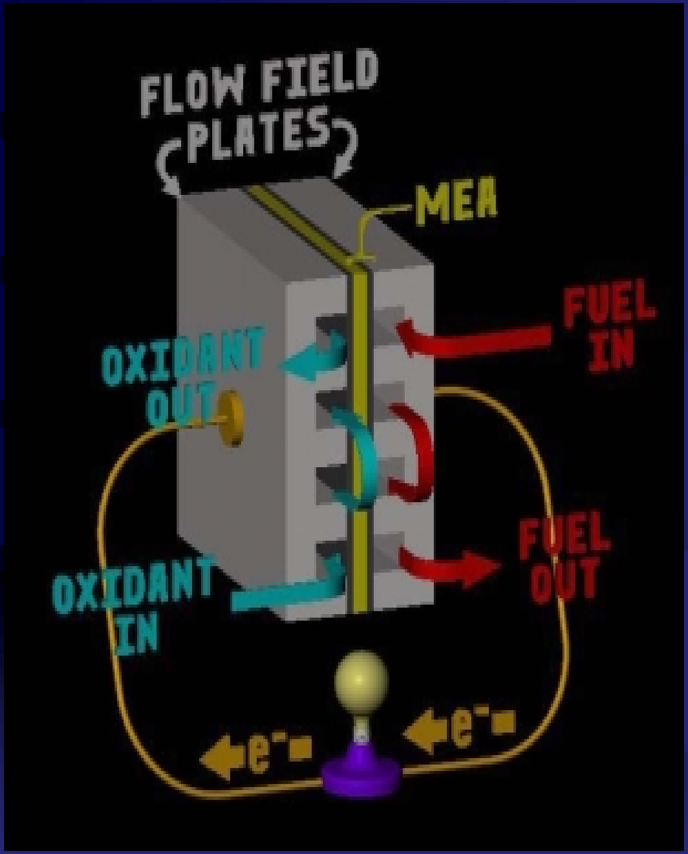
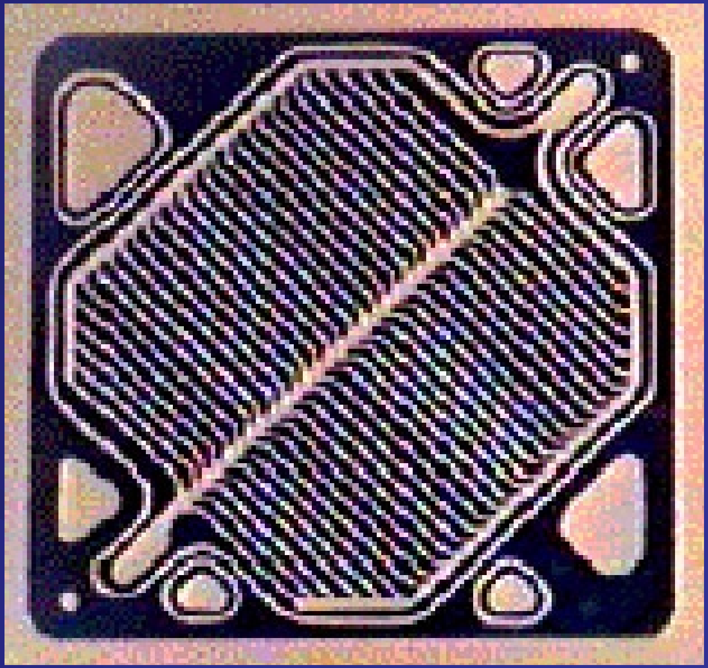
Fuel Cell Fuel and Oxidant Delivery Plate





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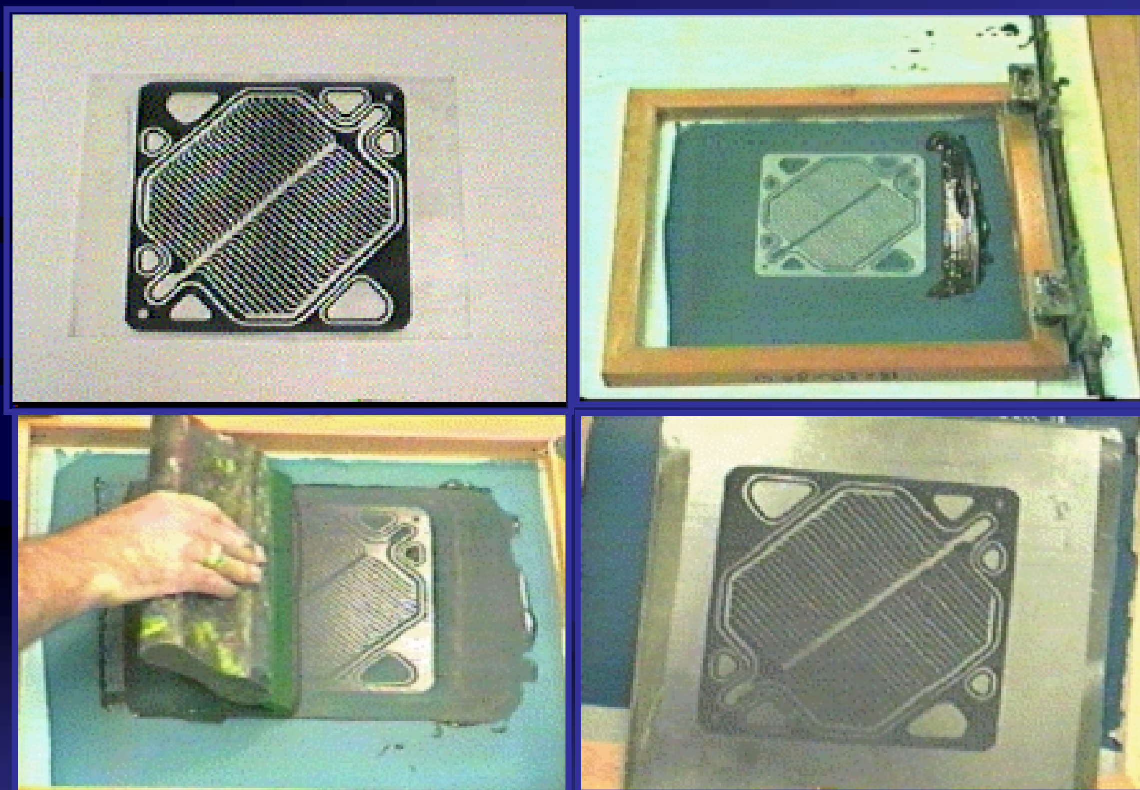
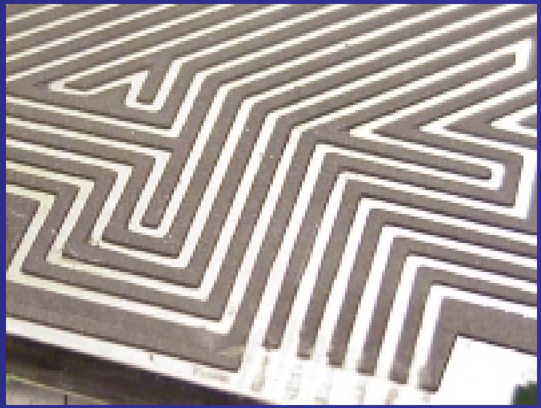
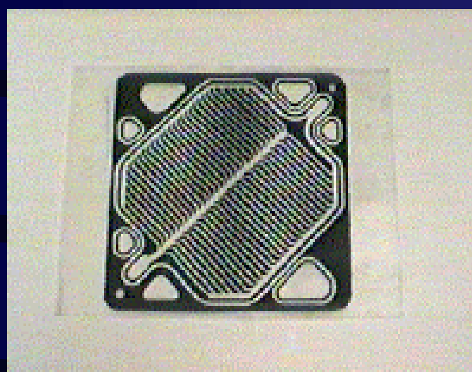


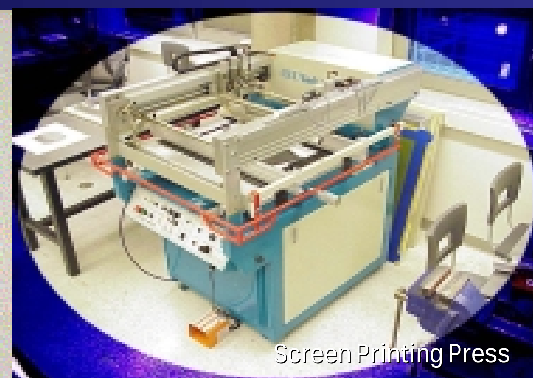


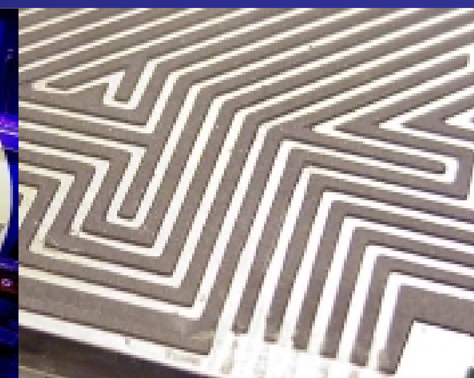
Major Research Targets

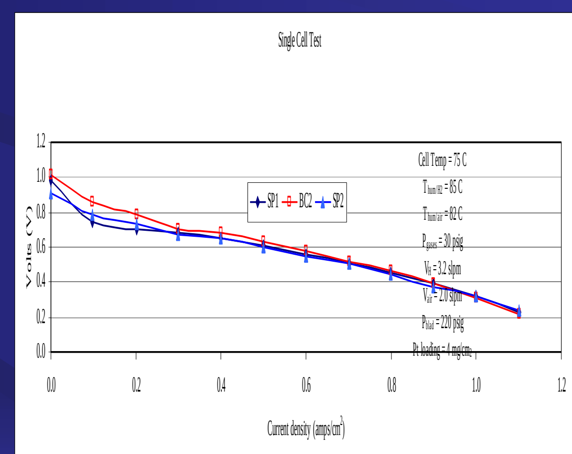
- **Process feasibility – low cost manufacturing**
  - build up the height and complex shape of flow channel walls
  - stencil material and automated stencil production process
  - tolerance control and process details
  - prototype, batch and mass production at ($2~5/plate)
- **Plate stability and zero contamination**
  - corrosive, humid & heated working conditions
  - ink base and ink ingredients (poster ink, conductive polymer, castable graphite, composite material, etc.)
  - printing process and post processing
- **Eliminating/reducing contact resistance**
  - wet assembly, laminated copper-graphite foils

Screen Printing Fuel and Oxidant Delivery Plate Manufacturing Method









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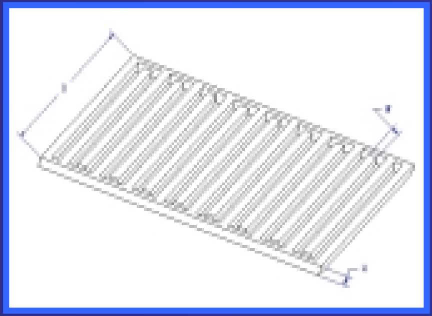
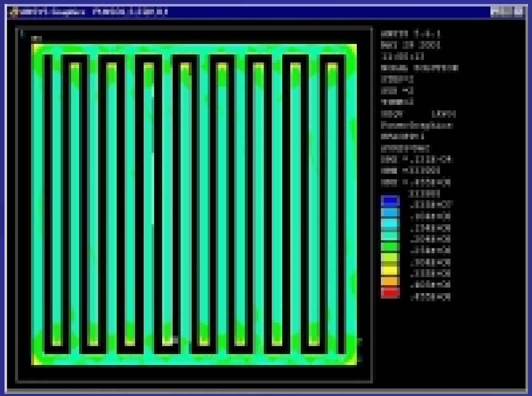
Rapid Prototype Development of Fuel Cell Gas Delivery Plate Using Virtual Prototyping, Optimization and Screen Printing

- **Plate Structure Design & Optimization**
  - design of plate geometry
    flow field layout and plate geometry
    (CFD & FEA) (30% more oxygen)
  - design of composite material
    property and composition (FEA, etc.)
  - testing of composite materials
- **Rapid Prototyping**
  - stencil making
  - plate making
  - fuel cell testing (23% more power)





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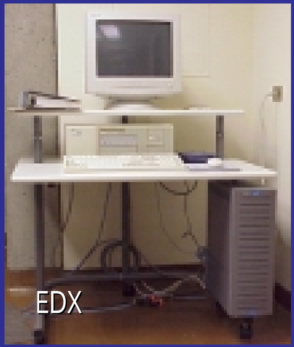
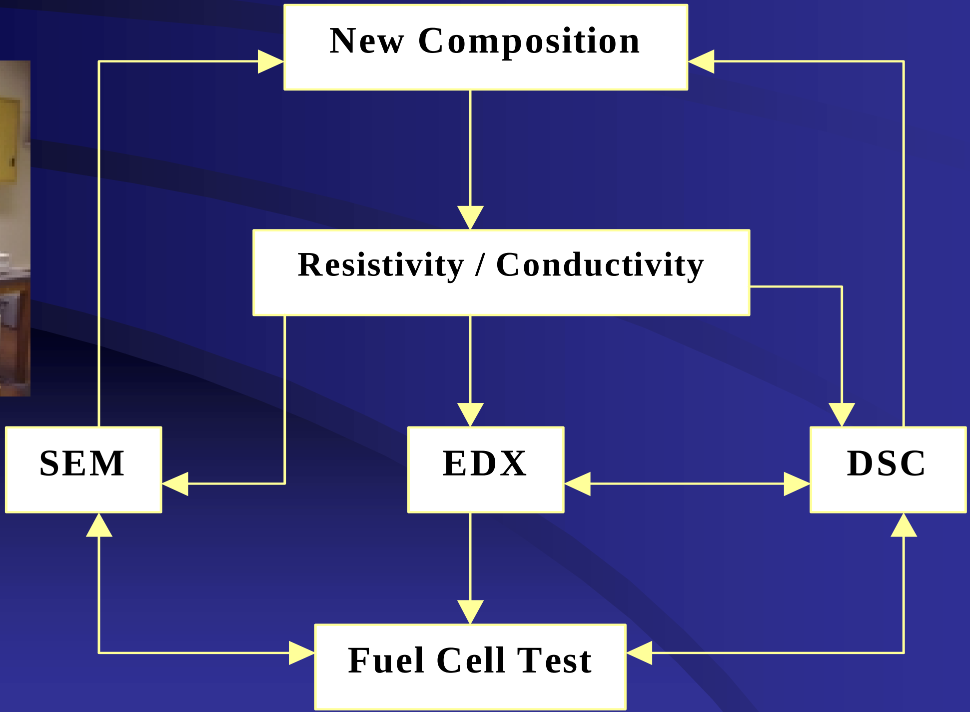
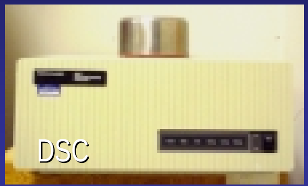
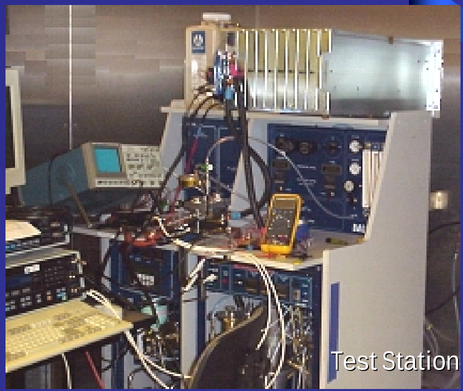
Testing of New Composite Materials

- Resistivity
- SEM (Scanning Electronic Microscope) (microstructure)
- EDX (Energy Dispersive X-ray) (spectrum of active ions)
- DSC (Differential Scanning Calorimeter) (vapor evaporation)
- Fuel Cell Test (performance)









PEM Fuel Cell Research of Our Group at University of Victoria

- **Next Generation Fuel Cells for Transportation** (94~99)
  - Part of the IESVic *CRD* Grant by NSERC, British Gas Canada and Ballard Power Systems Ltd.
  - Four Related Areas:

    Radiator Stack Design; Low Cost, Rapid Prototype Development of Fuel Cell Plates; Fuel Cell Stack and System Modeling; and Concurrent Engineering Design through Global Optimization.

- **Fuel Cell Powered Electrical Bicycles** (2000 ~ present)
  - Mathematical Modeling of the Fuel Cell Systems for Powering Electrical Bicycles and Scooters
  - Testing Methods and Procedures for Electrical Bicycles
  - Virtual Prototyping of Fuel Cell E-Bicycles and E-Scooters

Concept Fuel Cell Powered Mountain Bicycle and Control System

- A concept fuel cell powered bicycle built on a Rocky Mountain Bicycles RM6 full suspension bicycle.
- Due to the front motorized drive, the power system can be easily fitted to any bicycle.

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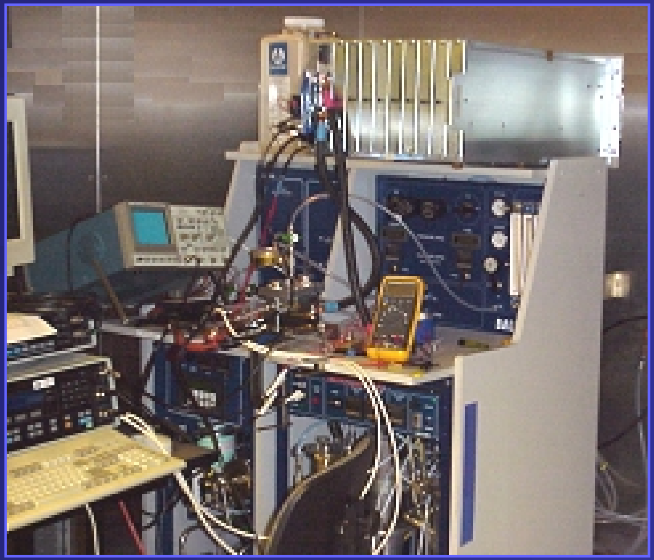
Fuel Cell and E-Bicycle Testing Facilities



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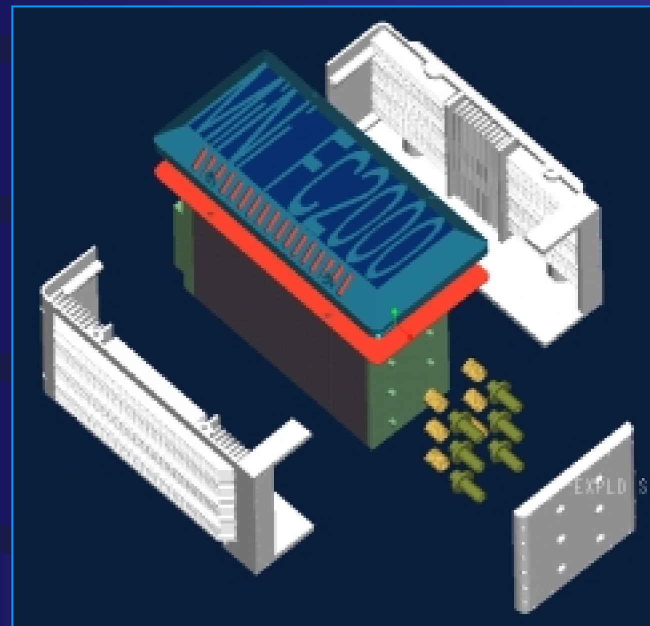
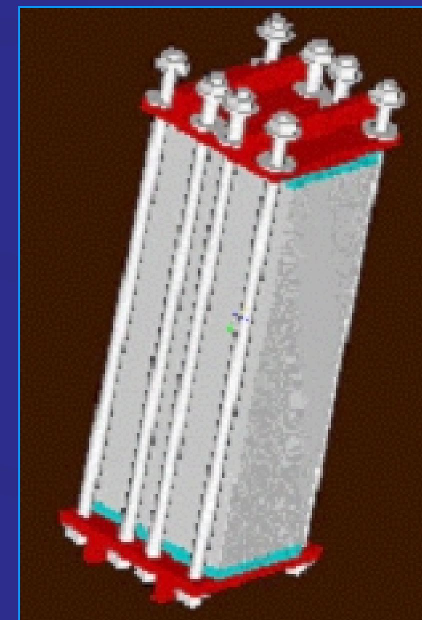
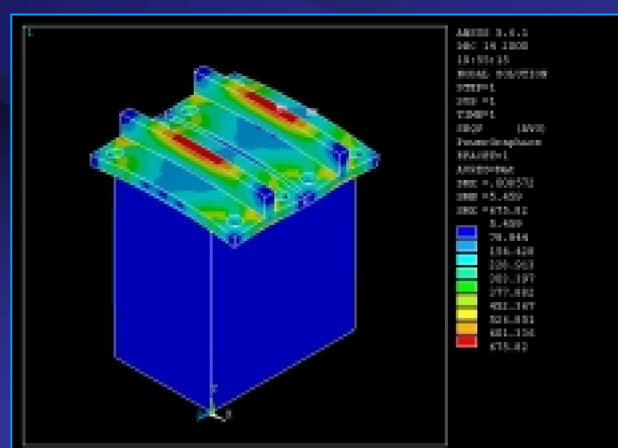
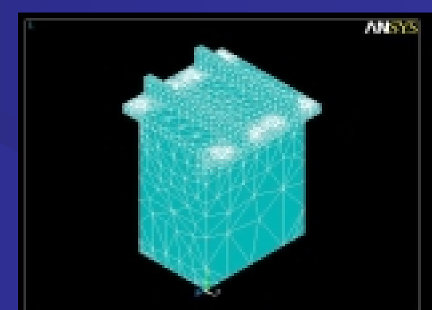
Concept Fuel Cell Stack and E-Bicycle Design, Modeling and Analysis









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